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ABSTRACT

A description of the general characteristics of sludge is provided in this lesson. It is intended as introductory material to acquaint students with the physical, chemical and biological characteristics of sludge. The lesson includes an instructor's guide and student workbook. The instructor's guide contains a description of the lesson, estimated presentation time, instructional materials list, suggested sequence of presentation, reading lists, objectives, lecture outline, narrative of the slide/tape program used with the lesson, and student worksheet (with answers). The student workbook contains objectives, glossary, discussion of sludge characteristics, references, and worksheet. (JN)

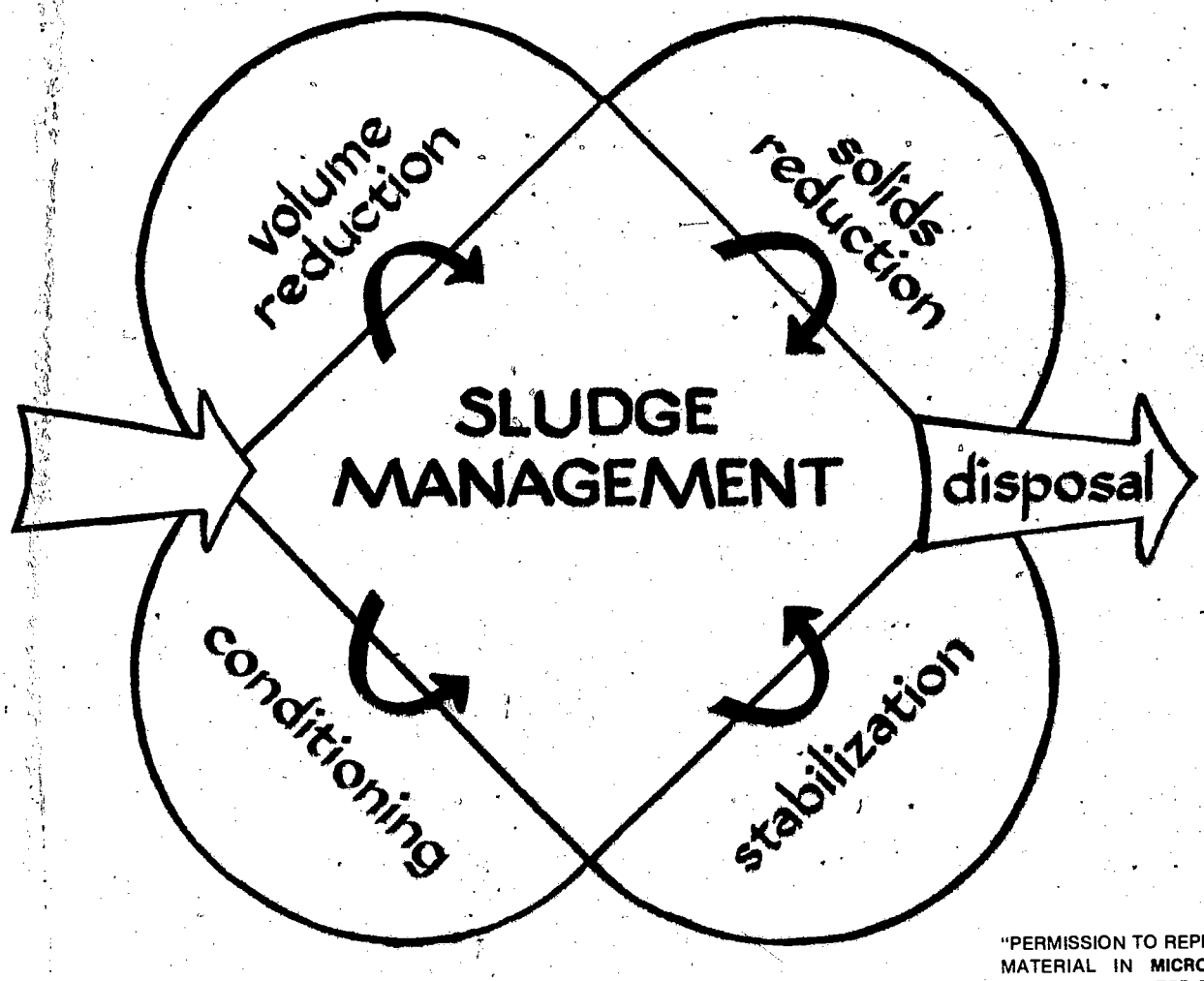
SLUDGE TREATMENT

and

DISPOSAL

COURSE # 166

SLUDGE CHARACTERISTICS



INSTRUCTOR'S GUIDE

Prepared by
Linn-Benton Community College
and
Envirotech Operating Services

SLUDGE CHARACTERISTICS

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SLUDGE CHARACTERISTICS

CONTENTS

SLUDGE CHARACTERISTICS

Lesson Description

This lesson is a description of the general characteristics of sludge. It is intended as introductory material to acquaint the student with the physical, chemical and biological characteristics of sludge. This material should be reviewed prior to a discussion of sludge conditioning or the consideration of any sludge treatment process.

Estimated Time

Student preview of objectives	5-10 minutes
Presentation of material	30-40 minutes
Worksheet	20-30 minutes
Correct worksheet and discussion	5-10 minutes

Instructional Materials List

1. Student text, "Sludge Characteristics"
2. Slide set, "Sludge Characteristics"
3. Slide projector and screen
4. Examples of primary and secondary sludge, settleometer, Imhoff Cone, Buchner Funnel and vacuum flash, evaporating dish, powdered milk, miniature marshmellows, raisins.

Suggested Sequence of Presentation

1. Assign reading.
2. Lecture and demonstration using slide format and outline. This material may also be presented in a slide/tape mode using a Wollensak cassette player coupled to a 35mm carousel projector. The tape is equipped with a non-audible cue to automatically advance and synchronize the slides.
3. Prior to using the slide material for this lesson, it may be helpful to discuss the types of solids in water. Solids are either settleable, floatable or dissolved (dispersed). Use a large beaker of water, throw in a handful of raisins - they settle - these are settleable solids. Now throw in a handful of marshmallows - they float - these are floating solids. Stir in ½ cup powdered milk - it dissolves - these are dissolved solids. State that solids in wastewater are either settleable (sinkers), floatable (floaters), or dissolved (lurkies).
4. Assign worksheet.
5. Review worksheet.

Required Reading

EPA Course #166, "Sludge Characteristics".

Reference Reading

"Process Design Manual for Sludge Treatment and Disposal", U.S.E.P.A., September, 1979, EPA 625/1-79-011.

"Treatment and Disposal of Wastewater Sludges", P. Aarne Vesilind, 1979, Pages 17-39.

Objectives

Upon completion of this lesson the student should be able to do the following:

1. Recall that specific gravity is the ratio of $\frac{\text{wt. of material}}{\text{wt. of equiv. vol. } H_2O}$
2. Recall that most sludges have S.G. greater than 1.0.
3. Define suspended solids as that fraction which does not pass through a fiber filter under standard test conditions.
4. Define dissolved solids as that fraction which passes through a fiber filter under standard test conditions.
5. Define total solids as the sum of suspended solids and dissolved solids.
6. Define volatile solids as those which burn at 600^{o} C.
7. Define fixed solids as those which do not burn at 600^{o} C.
8. Describe the method for measuring total solids.
9. Describe the method for measuring % of moisture.
10. Recall that sludges can be described in terms of their settling characteristics.
11. Recall the definition of SVI for measuring settling characteristics of activated sludge.
12. Recall that sludge particle size varies with time.
13. Recall that sludge particles vary in size, consistency, and shape.
14. Recall that water associated with sludge exists in the following five categories:
    a) Free water
    b) Floc water
    c) Capillary water
    d) Bound water
    e) Intracellular water
15. Recall that sludge has a fuel value because of its volatile matter.
16. Recall that sludge has nutrients found in commercial fertilizers, but in smaller amounts.
17. Recall that sludge's fertilizer value may be influenced by the presence of heavy metals or chlorinated hydrocarbons.

18. Recall that sludge has an electrical charge surrounding each particle.

19. Recall that one of the biological characteristics of sludge is the presence of pathogenic organisms.

SLUDGE CHARACTERISTICS

OUTLINE

I. WASTEWATER COMPOSITION

- A. Water - 99.9% By Weight
- B. Solids - 0.1% By Weight
- C. Example Of Per Capita Contribution
  1. 10,000 people = 5,000 lbs. solids per day

II. DEFINITION OF TERMS

- A. Pretreatment - Effect On Sludge
- B. Sludge - Slurry Of Solids And Water
  1. Primary - settleable
  2. Secondary - biological
  3. Chemical
- C. Floaters - Scum, Grease & Synthetics
- D. Biological Conversion Of Dissolved And Colloidal Matter
- E. Chemical Conditioning
  1. Settling
  2. Dewatering

III. WASTEWATER CHARACTERISTICS

- A. Solids Concentration
  1. Weight/volume - mg/l
  2. % of solids
- B. Total Solids
- C. Volatile Solids - Organic
- D. Fixed Solids - Inorganic
- E. Dissolved Solids
- F. Suspended Solids

G. Moisture Content

H. Specific Gravity

I. Settleability

1. Imhoff cone - settleable solids

2. Settleometer - SVI

IV. FORMS OF WATER IN SLUDGE

A. Free Water - Remove By Gravity

B. Floc Water - Remove Mechanically

C. Capillary Water - Reshape Particles To Remove

D. Bound Water - Not Removed By Mechanical Means

E. Intracellular Water - Burst Cell To Remove

V. FACTORS AFFECTING SLUDGE CHARACTERISTICS

A. Time - Affects Size And Shape

B. Type

1. Primary is fibrous, dewaters well

2. Secondary - dewaters more poorly

3. Chemical - depends on type of chemical

C. Electrical Charge

1. Influences flocculation

D. Fuel Value

1. Related to volatile solids and moisture content

E. Fertilizer

1. N, P, K

2. Heavy Metals

F. Pathogens

VI. QUANTITY OF SLUDGE

A. Dictated By Type Of Process

B. Primary Treatment - 40-60% S.S. Removal; 25-35% BOD Removal

C. Yield - 0.2 - 0.7 lbs./lb. BOD Removed

NARRATIVE

Slide #

1. This is an introductory module which discusses the types of sludges, sludge characteristics; and methods of measuring these characteristics. This module should be viewed prior to viewing specific unit process modules.

2. The module was written by Mr. Paul H. Klopping and edited by Dr. John W. Carnegie. The instructional development was done be Priscilla Hardin. Mr. Klopping was also the project director.

3. Wastewater is a mixture of solids and water. Water makes up 99.9% of wastewater. Solids account for the rest, about 1/10 of 1%. Even though this sounds like a small amount, pollution and health problems are associated with wastewater solids and treatment plants are designed and operated to remove solids from the used water before it is discharged to the environment.

4. A city of 10,000 people may send more than 5,000 pounds of wastewater solids per day down the drain and these must be removed by a treatment plant to protect water quality.

5. Initial treatment of influent wastewater involves the handling and removal of grit and screenings. This is called pretreatment. The design and operation of pretreatment facilities is sometimes overlooked. Since downstream operations are always affected by those upstream, sludge characteristics may be influenced by pretreatment.

6. Sludge is a term used to describe solids which are removed from wastewater after pretreatment. Sludge is actually a slurry of solids and liquid and may be thought of as one of three types: raw, biological, or chemical.

7. The solids that settle in a primary clarifier are referred to as raw or primary sludge.

8. This settleable fraction can be measured in an Imhoff cone, and it is called settleable solids.

9. Some solids, such as grease, oil and synthetics float to the surface of a primary clarifier, and these are collected as scum.

10. Any material that will neither settle nor float is passed on in the primary effluent and must be converted to a settleable form by some other process. These unsettleable solids are dissolved material and fine, suspended particles.

11. Much of the material [redacted] matter, which is changed by biological conversion in[redacted] settleable biological sludge. The clarified effluent left behind is free of most of its organic pollutants. This is the process of secondary treatment and the biological sludge produced is called secondary sludge.

12. Of course, the characteristics of secondary sludge are considerably different from raw sludge. The secondary sludge is composed principally of biological cells while the raw sludge is made up of coarse, fibrous matter.

13. Although not as common as biological treatment, chemical treatment can be used to convert nonsettling material to a settleable sludge. Primary effluent, and primary and secondary sludge can be converted to settleable chemical sludge by the addition of chemicals.

14. Chemical treatment offers several options. One option, called conditioning, enhances the settling and dewatering characteristics of primary or secondary sludge. Tentiary treatment, which is a third stage of treatment, following the secondary process is another option.

15. In some cases, wastewater solids are removed by chemical means alone. These facilities do not have typical primary and secondary processes. They simply use chemical coagulation and sedimentation to remove solids from the influent stream.

16. The origin of sludge should be thoroughly considered in the selection of any subsequent sludge handling or treatment process.

17. Three categories of sludge may be encountered. Raw or primary sludge is the settleable solids removed by primary sedimentation.

18. Biological or secondary sludge is produced by biological activity and removed by sedimentation.

19. And chemical sludge is produced by chemical addition and removed by sedimentation. Chemical sludges may be found in combination with primary and secondary sludge.

20. In order to optimize the design and operation of each sludge treatment process, one should know the quantity of solids a facility is expected to handle, and the characteristics of those solids.

21. In order to compare the quantity and characteristics of sludge from one day to the next it is important to have methods to measure the solids and liquids in the sludge.

22. The quantity of solids and liquids in sludge cna be determined by techniques involving burning dry solids and filtering the sludge slurry. Let's first look at the burning technique.

23. If sludge solids are heated to 600° Celcius, part of the material burns and is converted to a gas while the rest remains fixed as a residue, or ash. The fraction that burns at 600° Celcius is referred to as volatile solids, the fraction that remains is fixed solids or ash.

24. The volatile solids are a measure of the organic matter in sludge, while the fixed solids are a measure of the inorganics, such as sand and grit.

25. Sludge can be divided into two other fractions by filtration. Suspended solids are trapped on filter paper and dissolved solids pass through the filter with the water.

26. The weight of the suspended solids can be determined by evaporating the moisture and weighing the dryed material. The weight of the dissolved solids can also be found by evaporating the water away from the dissolved material and weighing the residue left behind.

27. The total solids, therefore, are the sum of the dissolved and suspended solids and each of these fractions is composed of a volatile and a nonvolatile portion.

28. The moisture content is another quantilative measurement of sludge. A knowledge of moisture content is important to the successful operation of most solids handling processes.

29. The moisture content can be expressed either in terms of the solids or the liquids. Two common methods of expressing solids concentration are mg/l and % solids.

30. Milligrams per liter is a weight to volume relationship. It is a measure of the milligrams of dry solids contained in one liter of sludge.

31. Solids concentration can also be expressed by % solids, which is a weight to weight relationship. It is a measure of the milligrams of dry solids contained in one liter of sludge.

32. When it is necessary to express % moisture rather than % solid concentration, this can be calculated by subtracting the % solids from 100%. A sludge that is 1% solids is 99% moisture.

33. Now let's look at some special characteristics of sludge.

34. The specific gravity of sludge determines whether it will settle or float.

35. Specific gravity compares the weight of a substance to the weight of an equivalent volume of water.

36. Water has a specific gravity of 1.0 at 4^{o} Celcius. Materials that float have specific gravities of less than 1.0, those that sink are greater than 1.0. Most sludges have specific gravities slightly greater than 1.0. If a liter of sludge weighs 1,010 g, and an equivalent volume of water weighs 1,000 g, the specific gravity is 1.01.

37. Raw sludge usually ahs a higher specific gravity than biological sludge. This is one reason why it settles and compacts well.

38. Another characteristic of sludge is its settleability. Settleability is a measure of the amount of sludge that will settle in a given period of time.

39. Raw sludge settleability is measured in a Imhoff cone, and the portion of sludge that settles in one liter is called settleable solids and is expressed in ml/l. This test gives an indication of the volume of sludge which may be removed by primary sedimentation.

40. Secondary sludge has different characteristics than raw sludge and generally settles slower. Secondary sludge settleability is measured in a wide-mouthed, graduated cylinder.

41. The most common measurement is the sludge volume index or (SVI) test.

42. SVI is the volume occupied by one gram of sludge after thirty minutes settling. It is calculated by multiplying the thirty minutes settled sludge volume by 1,000 and dividing by the mixed liquor suspended solids concentration in mg/l.

$$SVI = \frac{SSV_{30} \times 1{,}000}{MLSS\ (mg/l)}$$

43. An example will illustrate this calculation. If sludge weighing 2,000 mg/l settled to 200 ml after thirty minutes, SVI is:

$$\frac{200 \times 1{,}000}{2{,}000} = 100$$

44. An SVI of 100 or less represents a good settling sludge. As the SVI exceeds 100, sludge settling becomes slower and this may be troublesome. The best operating ranges for SVI are dependent on plant design and loading, and must be found for each facility through actual operating experience.

45. To understand the relationship between solids and water in sludge, it is important to know that the water in sludge exists in five forms; free water, floc water, capillary water, bound water and intracellular water.

46. Free water can be removed by simple gravitational settling, since it is not attached to sludge solids in any way.

47. Floc water is trapped within the floc and travels with it. Each floc particle is really a group of smaller particles, and as floc is compressed by mechanical means, water trapped bewteen the floc particles is squeezed out and removed.

48. Capillary water adheres between adjacent particles and can only be removed when the particles are forced out of shape and compacted. Bound water refers to a very thin layer, which is chemically bound to each individual particle. It is not removed by mechanical dewatering methods.

49. Intracellular water is contained inside biological cells and can only be removed by disrupting the cell. This water is typically removed by heat conditioning.

50. It is important to understand the forms of water that are present in the various types of sludge, because these different forms affect the ability of treatment processes to remove the water.

51. As sludge particles flocculate, that is clump together and grow larger, time becomes an important factor. The size, consistency, and shape of hte sludge particles also influence flocculation.

52. This is especially evident in biological sludge. The "curdly" appearance of good settling secondary sludge is due to particle attraction and interaction as it flocculates to form a sludge blanket and settles.

53. The relative dewaterability of sludge is an important characteristic and is influenced by the type of sludge. Raw sludge, because of its fibrous nature, dewaters well. Secondary sludge, because of its biological constituents, may contain considerable amounts of bound and intracellular water, making it more difficult to dewater. Chemical sludge vary in their dewaterability.

54. Alum sludge, for instance, has poorer dewatering characteristics than lime sludge becasue of the gelatinous nature of alum sludge.

55. Floc shear which refers to the tearing or breaking apart of floc when a force is applied to remove water contained within the floc. The floc may break apart and be carried away with the water.

56. Biological sludge are generally less likely to shear than chemical sludges.

57. The electrical charge characteristic of sludge has a great influence on chemical conditioning. Sludge usually has a net negative charge. Polymers and other chemical conditioners change the electrical charge of the particles, making them more flocculent.

58. Fuel value is another important characteristic. Sludge has a fuel value which is related to its volatile solids and moisture content.

59. When sludge is dry enough to burn, it releases energy just like any other volatile organic material. Coal, for instance, contains the equivalent of about 14,000 BTU per pound. However, since sludge is wet and only partially volatile it has a much lower BTU value. Auxiliary fuel is usually required in sludge combustion.

60. Sludge is sometimes disposed of on land and used as soil conditioner and fertilizer. Wastewater sludges are lower than commercial fertilizers in nitrogen, phosphorous and potassium content.

61. Sludge may accumulate heavy metals or chlorinated hydrocarbons, making it unsuitable for agricultural use. When this is not a problem, the fact that the sludge is a good soil conditioner and is a source of some essential nutrients makes land application a popular method of disposal. Raw sludge and secondary sludges contain pathogenic organisms.

62. Individual sludge treatment and disposal processes have varying effects on pathogenicity. Some, like incineration, render sludge entirely sterile, while others have no effect.

63. Quantities of sludge to be handled by a facility are dependent on overall plant design and loading.

64. Primary sedimentation can be expected to remove 40-60% of the suspended solids that enter the plant.

65. Secondary treatment produces varying amounts of sludge depending on its design, efficiency, and mode of operation. For example, from 0.2 - 0.7 lb. of sludge may be produced per pound of BOD removed.

66. Whether during design, during normal operation, or during upset, attention must be given to the quantity and characteristics of sludge to be handled.

Percent moisture, total, volatile, and suspended solids should be determined. haracteristics such as specific gravity, types of water in the floc, and fuel value, should be considered.

67. The successful production of an acceptable final effluent begins and ends with the ability to control and handle wastewater solids.

SLUDGE CHARACTERISTICS

WORKSHEET

1. Specific gravity is the ratio between the weight of a material and an equivalent volume of:

   ____ A. Sludge

   ____ B. Air

   __X__ C. Water

   ____ D. Ice

   ____ E. Iron

2. Most sludges have specific gravities greater than:

   __X__ A. 1.0

   ____ B. 1.5

   ____ C. 2.0

   ____ D. 2.5

   ____ E. 3.0

3. The fraction of solids which is trapped on filter paper under standard test conditions is called:

   ____ A. Dissolved solids

   ____ B. Total solids

   __X__ C. Suspended solids

   ____ D. Volatile solids

   ____ E. Colloidal solids

4. The fraction of solids which passes through the fiber filter and may be measured by evaporation, is called:

   __X__ A. Dissolved solids

   ____ B. Total solids

   ____ C. Suspended solids

   ____ D. Volatile solids

   ____ E. Colloidal solids

5. Solids which burn at 600° C., are called:

_____ A. Dissolved solids

_____ B. Total solids

_____ C. Suspended solids

__X__ D. Volatile solids

_____ E. Colloidal solids

6. Percent moisture is:

__X__ A. 100% - % solids

_____ B. 100 - mg/l solids

_____ C. % solids - 100

_____ D. mg/l solids - 100

_____ E. None of the above

7. Mixed liquor suspended solids = 3,000 mg/l. It settles to 300 ml in 30 minutes. What is the calculated sludge volume index (SVI)?

_____ A. 300

_____ B. 3000

_____ C. 200

__X__ D. 100

_____ E. None of the above

8. How does time affect sludge particle size?

_____ A. Size increases

_____ B. Size decreases

_____ C. Size stays the same

__X__ D. All of the above

_____ E. None of the above

9. Sludge particles may vary in:

_____ A. Size

_____ B. Consistency

_____ C. Shape

__X__ D. All of the above

_____ E. None of the above

10. Matching: Choose the answer from Column "B" which best describes each term in Column "A".

Column A	Column B
__C__ Free water	A. A very thin layer which is chemically attached and is not removed by mechanical dewatering.
__D__ Floc water	
__E__ Capillary water	B. Contained inside biological cells and is released upon thermal conditioning.
__A__ Bound water	
__B__ Intracellular water	C. Removed by simple gravitational settling.
	D. Is squeezed out when mechanically compressed.
	E. Adheres between adjacent particles and is removed when particles are forced out of shape and compacted.

11. What accounts for the fuel value in sludge?

_____ A. Total solids

__X__ B. Volatile solids

_____ C. % moisture

_____ D. Suspended solids

_____ E. Dissolved solids

12. With regard to the fertilizer value of sludge:

_____ A. It is higher in nutrients than commercial fertilizer.

_____ B. It is high in nitrogen.

__X__ C. It is lower in most nutrients than that found in commercial fertilizer.

_____ D. It is equivalent to commercial fertilizer.

_____ E. None of the above.

13. What is (are) drawback(s) to the use of sludge as a fertilizer?

_____ A. Presence of too many nutrients.

_____ B. Presence of pathogens.

_____ C. Presence of heavy metals.

_____ D. A & B are both correct.

__X__ E. B & C are both correct.

14. The surface of a sludge particle plays a role in affecting its flocculation characteristics. This is due to:

_____ A. The presence of an electrical charge.

_____ B. The presence of filamentous bacteria.

_____ C. The presence of viable microorganisms.

__X__ D. A & B are correct.

_____ E. B & C are correct.

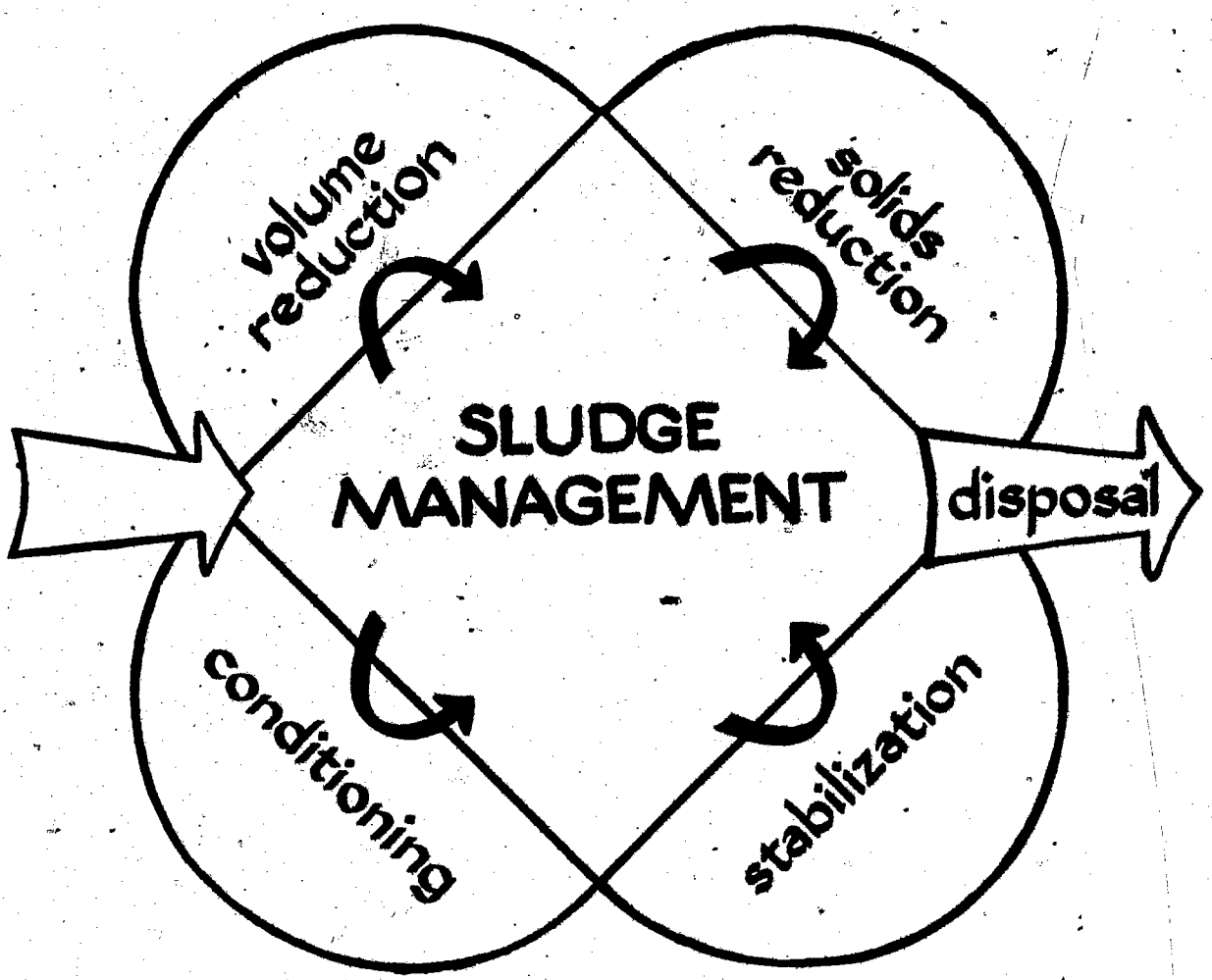
SLUDGE TREATMENT

and

DISPOSAL

COURSE # 166

SLUDGE CHARACTERISTICS



STUDENT WORKBOOK

Prepared by
Linn-Benton Community College
and
Envirotech Operating Services

SLUDGE CHARACTERISTICS

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SLUDGE CHARACTERISTICS

CONTENTS

Objectives

Upon completion of this lesson the student should be able to do the following:

1. Recall that specific gravity is the ratio of $\frac{\text{wt. of material}}{\text{wt. of equiv. vol. } H_2O}$
2. Recall that most sludges have S.G. greater than 1.0.
3. Define suspended solids as that fraction which does not pass through a fiber filter under standard test conditions.
4. Define dissolved solids as that fraction which passes through a fiber filter under standard test conditions.
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6. Define volatile solids as those which burn at 600° C.
7. Define fixed solids as those which do not burn at 600° C.
8. Describe the method for measuring total solids.
9. Describe the method for measuring % of moisture.
10. Recall that sludges can be described in terms of their settling characteristics.
11. Recall the definition of SVI for measuring settling characteristics of activated sludge.
12. Recall that sludge particle size varies with time.
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14. Recall that water associated with sludge exists in the following five categories:
    a) Free water
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15. Recall that sludge has a fuel value because of its volatile matter.
16. Recall that sludge has nutrients found in commercial fertilizers, but in smaller amounts.
17. Recall that sludge's fertilizer value may be influenced by the presence of heavy metals or chlorinated hydrocarbons.

18. Recall that sludge has an electrical charge surrounding each particle.

19. Recall that one of the biological characteristics of sludge is the presence of pathogenic organisms.

SLUDGE CHARACTERISTICS

GLOSSARY

B.O.D. - The quantity of oxygen required by microorganisms while stabilizing decomposable organic matter under aerobic conditions and other test conditions.

BTU - British Thermal Unit. The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Floc - Small, gelatinous masses formed in a liquid by the reaction of coagulants thereto, through chemical or biochemical processes, or by agglomeration.

Imhoff Cone - A clear, cone-shaped container marked with graduations used to measure the volumetric concentration of settleable solids in wastewater.

Pathogens - Disease-producing organisms.

Pretreatment - Use of racks, screens, comminutors, and grit removal devices to remove metal, rocks, sand, eggshells, and similar materials which may hinder operation of a treatment plant.

Primary Treatment - The first major (sometimes the only) treatment in a sewage treatment works, usually sedimentation. The removal of a high percentage of suspended matter but little or no colloidal and dissolved matter.

Secondary Treatment - (1) The treatment of sewage by biological methods after primary treatment by sedimentation. (2) A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated.

Sludge - (1) The settleable solids separated from liquids during processing or deposits on bottoms of streams or other bodies of water. (2) The accumulated settled solids deposited from sewage or industrial wastes, raw or treated, in tanks or basins, and containing more or less water to form a semi-liquid mass.

Sludge Volume Index - The sludge volume index is the volume in milliliters occupied by one gram of activated sludge after settling for thirty minutes. The formula for finding the sludge volume index is as follows:

$$\frac{\text{ml of settled solids}}{\text{MLSS}} \times 1{,}000 = \text{Sludge Volume Index}$$

Specific Gravity - The weight of a substance when compared to an equivalent volume of water. Water has a specific gravity of 1.00 at 4° C.

Suspended Solids - (1) The quantity of material deposited when a quantity of water, sewage, or other liquid is filtered through an asbestos mat in a Gooch crucible. (2) Solids that either float on the surface of, or are in suspension, in water, sewage, or other liquids, and which are largely removable by laboratory filtering.

Tertiary Treatment - A third stage of treatment, following secondard treatment. May consist of physical and/or chemical treatment.

SLUDGE CHARACTERISTICS

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The module was written by Mr. Paul H. Klopping and edited by Dr. John W. Carnegie. The instructional development was done by Priscilla Hardin. Mr. Klopping was also the project director.

WASTEWATER
99.9% pure water
0.1% solids

Wastewater is a mixture of solids and water. Water makes up 99.9% of wastewater. Solids account for the rest, about 1/10 of 1%. Even though this sounds like a small amount, pollution and health problems are associated with wastewater solids and treatment plants are designed and operated to remove solids from the used water before it is discharged to the environment.

A city of 10,000 people may send more than 5,000 pounds of wastewater solids per day down the drain and these must be removed by a treatment plant to protect water quality.

PRETREATMENT
***screening**
***grinding**
***grit removal**

. . . influences sludge characteristics

Initial treatment of influent wastewater involves the handling and removal of grit and screenings. This is called pretreatment. The design and operation of pretreatment facilities is sometimes overlooked. Since downstream operations are always affected by those upstream, sludge characteristics may be influenced by pretreatment.

WHAT IS SLUDGE? Sludge is a term used to describe solids which are removed from wastewater after pretreatment. Sludge is actually a slurry of solids and liquid and may be thought of as one of three types: raw, biological, or chemical.

The solids that settle in a primary clarifier are referred to as raw or primary sludge.

This settleable fraction can be measured in an Imhoff cone, and it is called settleable solids.

Some solids, such as grease, oil and synthetics float to the surface of a primary clarifier, and these are collected as scum.

BIOLOGICAL CONVERSION
***results in secondary sludge**

Any material that will neither settle nor float is passed on in the primary effluent and must be converted to a settleable form by some other process. These unsettleable solids are dissolved material and fine, suspended particles.

Much of the material is organic matter, which is changed by biological conversion into settleable biological sludge.

The clarified effluent left behind is free of most of its organic pollutants. This is the process of secondary treatment and the biological sludge produced is called secondary sludge.

Of course, the characteristics of secondary sludge are considerably different from raw sludge. The secondary sludge is composed principally of biological cells while the raw sludge is made up of coarse, fibrous matter.

CHEMICAL CONVERSION
***results in chemical sludge**

Although not as common as biological treatment, chemical treatment can be used to convert non-settling material to a settleable sludge. Primary effluent, and primary and secondary sludge can be converted to settleable chemical sludge by the addition of chemicals.

Chemical treatment offers several options. One option, called conditioning, enhances the settling and dewatering characteristics of primary or secondary sludge. Tentiary treatment, which is a third stage of treatment, following the secondary process is another option.

In some cases, wastewater solids are removed by chemical means alone. These facilities do not have typical primary and secondary processes. They simply use chemical coagulation and sedimentation to remove solids from the influent stream.

The origin of sludge should be thoroughly considered in the selection of any subsequent sludge handling or treatment process.

SLUDGE TYPES
***Primary**
***Secondary**
***Chemical**

Three categories of sludge may be encountered. Raw or primary sludge is the settleable solids removed by primary sedimentation.

Biological or secondary sludge is produced by biological activity and removed by sedimentation.

And chemical sludge is produced by chemical addition and removed by sedimentation. Chemical sludges may be found in combination with primary and secondary sludge.

In order to optimize the design and operation of each sludge treatment process, one should know the quantity of solids a facility is expected to handle, and the characteristics of those solids.

In order to compare the quantity and characteristics of sludge from one day to the next it is important to have methods to measure the solids and liquids in the sludge.

The quantity of solids and liquids in sludge can be determined by techniques involving burning dry solids and filtering the sludge slurry. Let's first look at the burning technique.

VOLATILE SOLIDS
***A fraction of total solids**
***Burn at 600°C**

If sludge solids are heated to 600° C, part of the material burns and is converted to a gas while the rest remains fixed as a residue, or ash. The fraction that burns at 600° C is referred to as volatile solids, the fraction that remains is fixed solids or ash.

FIXED SOLIDS
***Won't burn**
***Inorganics**

The volatile solids are a measure of the organic matter in sludge, while the fixed solids are a measure of the inorganics, such as sand and grit.

SUSPENDED SOLIDS
***trapped on filter paper**

Sludge can be divided into two other fractions by filtration. Suspended solids are trapped on the filter paper and dissolved solids pass through the filter paper with the water.

DISSOLVED SOLIDS
***measure by evaporation**

The weight of the suspended solids can be determined by evaporating the moisture and weighing the dryed material. The weight of the dissolved solids can also be found by evaporating the water away from the dissolved material and weighing the residue left behind.

TOTAL SOLIDS
***Dissolved Solids**
***Suspended Solids**

The total solids, therefore, are the sum of the dissolved and suspended solids and each of these fractions is composed of a volatile and a non-volatile portion.

MOISTURE CONTENT
***how much water?**
***100 - % solids**

The moisture content is another quantilative measurement of sludge. A knowledge of moisture content is important to the successful operation of most solids handling processes.

The moisture content can be expressed either in terms of the solids or the liquids. Two common methods of expressing solids concentration are mg/l and % solids.

Milligrams per liter is a weight to volume relationship. It is a measure of the milligram of dry solids contained in one liter of sludge.

SOLIDS CONCENTRATION
***How much is water and how much is solid matter**

Solids concentration can also be expressed by % solids, which is a weight to weight relationship. It is a measure of the milligrams of dry solids contained in a given weight of sludge.

WEIGHT/VOLUME
***mg/l**
***% solids**

When it is necessary to express % moisture rather than % solid concentration, this can be calculated by subtracting the % solids from 100. A sludge that is 1% solids is 99% moisture.

SLUDGE CHARACTERISTICS

Now let's look at some special characteristics of sludge.

SPECIFIC GRAVITY
***Settle?**
***Float?**

The specific gravity of sludge determines whether it will settle or float.

Specific gravity compares the weight of a substance to the weight of an equivalent volume of water.

Water has a specific gravity of 1.0 at 4° C. Materials that float have specific gravities of less than 1.0, those that sink are greater than 1.0. Most sludges have specific gravities weighs 1,010 g, and an equivalent volume of water weighs 1,000 g, the specific gravity is 1.01.

Raw sludge usually has a higher specific gravity than biological sludge. This is one reason why it settles and compacts well.

SETTLEABILITY
***Imhoff cone--settleable solids**
***Raw sludge**

Another characteristic of sludge is its settleability. Settleability is a measure of the amount of sludge that will settle in a given period of time.

Raw sludge settleability is measured in an Imhoff cone, and the portion of sludge that settles in one liter, expressed in ml/l, is called settleable solids. This test gives an indication of the volume of sludge which may be removed by primary sedimentation.

SETTLEABILITY
***Settleometer**
***Secondary sludge**

Secondary sludge has different characteristics than raw sludge and generally settles slower. Secondary sludge settleability is measured in a wide-mouthed, graduated cylinder.

The most common measurement is the sludge volume index (SVI) test. SVI is the volume occupied by one gram of sludge after thirty minutes settling.

SLUDGE VOLUME INDEX (SVI)
***30 minute settleability**

It is calculated by multiplying the thirty minutes settled sludge volume by 1,000 and dividing by the mixed liquor suspended solids concentration in mg/l.

$$SVI = \frac{SSV_{30} \times 1{,}000}{MLSS\ (mg/1)}$$

An example will illustrate this calculation. If sludge weighing 2,000 mg/l settled to 200 ml after thirty minutes, SVI is:

$$\frac{200 \times 1{,}000}{2{,}000} = 100$$

An SVI of 100 or less represents a good settling sludge. As the SVI exceeds 100, sludge settling becomes slower and this may be troublesome. The best operating ranges for SVI are dependent on plant design and loading, and must be found for each facility through actual operating experience.

What types of water are found in sludge?

***Free water**
***Floc water**
***Capillary water**
***Bound water**
***Intracellular water**

To understand the relationship between solids and water in sludge, it is important to know that the water in sludge exists in five forms; free water, floc water, capillary water, bound water and intracellular water.

FREE WATER
*drains by gravity

Free water can be removed by simple gravitational settling, since it is not attached to sludge solids in any way.

FLOC WATER
*squeezed out mechanically

Floc water is trapped within the floc and travels with it. Each floc particle is really a group of smaller particles, and as floc is compressed by mechanical means, water trapped between the floc particles is squeezed out and removed.

CAPILLARY WATER
*must change particle shape to remove it

BOUND WATER
*Chemically attached
*Not removed by mechanical means

Capillary water adheres between adjacent particles and can only be removed when the particle are forced out of shape and compacted. Bound water refers to a very thin layer, which is chemically bound to each individual particle. It is not removed by mechanical dewatering methods.

INTRACELLULAR WATER
*inside cells

Intracellular water is contained inside biological cells and can only be removed by disrupting the cell. This water is typically removed by heat conditioning.

It is important to understand the forms of water that are present in the various types of sludge, because these different forms affect the ability of treatment processes to remove the water from the sludge.

HOW IS SLUDGE INFLUENCED BY TIME?

As sludge particles flocculate, that is clumping together and growing larger, time becomes an important factor. The size, consistency, and shape of the sludge particles influence flocculation.

This is especially evident in biological sludge. The "curdly" appearance of good settling secondary sludge is due to particle attraction and,

interaction as it flocculates to form a sludge blanket and settles.

DEWATERABILITY
***varies with type of sludge**

The relative dewaterability of sludge is an important characteristic and is influenced by the Type of sludge. Raw sludge, because of its fibrous nature, dewaters well. Secondary sludge, because of its biological constituents, may contain considerable amounts of bound and intracellular water, making it more difficult to dewater. Chemical sludges vary in their dewaterability.

Alum sludge, for instance, has poorer dewatering characteristics than lime sludge because of the gelatinous nature of alum sludge.

Floc shear refers to the tearing or breaking apart of floc when a force is applied to remove water contained within the floc. The floc may break apart and be carried away with the water.

Biological sludges are generally less likely to shear than chemical sludges.

ELECTRICAL CHARGE
***surrounds particles**

The electrical charge characteristic of sludge has a great influence on chemical conditioning. Sludge usually has a net negative charge. Polymers and other chemical conditioners change the electrical charge of the particles, making them more flocculent.

FUEL VALUE
***due to volatile solids**

Fuel value is another important characteristic. Sludge has a fuel value which is related to its volatile solids and moisture content.

When sludge is dry enough to burn, it releases energy just like any other volatile organic mat-

erial. Coal, for instance, contains the equivalent of about 14,000 BTU per pound. However, since sludge is wet and only partially volatile it has a much lower BTU value. Auxiliary fuel is usually required in sludge combustion.

FERTILIZER VALUE
***low in nutrients**
***potential toxic compounds**
***soil conditioner**

Sludge is sometimes disposed of on land and used as soil conditioner and fertilizer. Wastewater sludges are lower than commercial fertilizers in nitrogen, phosphorous and potassium content.

Sludge may accumulate heavy metals or chlorinated hydrocarbons, making it unsuitable for agricultural use. When this is not a problem, the fact that the sludge is a good soil conditioner and is a source of some essential nutrients make land application a popular method of disposal.

Raw sludge and secondary sludges contain pathogenic organisms.

PATHOGENS?

Individual sludge treatment and disposal processes have varying effects on pathogenicity. Some, like incineration, render sludge entirely sterile, while others have no effect.

HOW MUCH SLUDGE WILL BE HANDLED?

Quantities of sludge to be handled by a facility are dependent on overall plant design and loading.

Primary sedimentation can be expected to remove 40-60% of the suspended solids that enter the plant.

Secondary treatment produces varying amounts of sludge depending on its design, efficiency, and mode of operation. For example, from 0.2 - 0.7 lb. of sludge may be produced per pound of BOD removed.

Whether during design, during normal operation, or during upset, attention must be given to the quantity and characteristics of sludge to be handled.

Percent moisture total, volatile, and suspended solids should be determined. Characteristics such as specific gravity, types of water in the floc, and fuel value, should be considered.

EFFLUENT QUALITY
***Dependent on solids handling**

The successful production of an acceptable final effluent begins and ends with the ability to control and handle wastewater solids.

REFERENCES:

Process Design Manual for Sludge Treatment and Disposal, U.S.E.P.A., September, 1979, EPA 625/1-79-011.

Treatment and Disposal of Wastewater Sludges, P. Aarne Vesilind, 1979. Pages 17-39.

Operation of Wastewater Treatment Plants, Manual of Practice No. 11, Water Pollution Control Federation.

SLUDGE CHARACTERISTICS

WORKSHEET

1. Specific gravity is the ratio between the weight of a material and an equivalent volume of:

_____ A. Sludge

_____ B. Air

_____ C. Water

_____ D. Ice

_____ E. Iron

2. Most sludges have specific gravities greater than:

_____ A. 1.0

_____ B. 1.5

_____ C. 2.0

_____ D. 2.5

_____ E. 3.0

3. The fraction of solids which is trapped on filter paper under standard test conditions is called:

_____ A. Dissolved solids

_____ B. Total solids

_____ C. Suspended solids

_____ D. Volatile solids

_____ E. Colloidal solids

4. The fraction of solids which passes through the fiber filter and may be measured by evaporation is called:

_____ A. Dissolved solids

_____ B. Total solids

_____ C. Suspended solids

_____ D. Volatile solids

_____ E. Colloidal solids

5. Solids which burn at 600° C. are called:

_____ A. Dissolved solids

_____ B. Total solids

_____ C. Suspended solids

_____ D. Volatile solids

_____ E. Colloidal solids

6. Percent moisture is:

_____ A. 100% - % solids

_____ B. 100 - mg/l solids

_____ C. % solids - 100

_____ D. mg/l solids - 100

_____ E. None of the above

7. Mixed liquor suspended solids = 3,000 mg/l. It settles to 300 ml in 30 minutes. What is the calculated sludge volume index (SVI)?

_____ A. 300

_____ B. 3000

_____ C. 200

_____ D. 100

_____ E. None of the above

8. How does time affect sludge particle size?

_____ A. Size increases

_____ B. Size decreases

_____ C. Size stays the same

_____ D. All of the above

_____ E. None of the above

9. Sludge particles may vary in:

_____ A. Size

_____ B. Consistency

_____ C. Shape

_____ D. All of the above

_____ E. None of the above

10. Matching: Choose the answer from Column "B" which best describes each term in Column "A".

Column A	Column B
_____ Free water	A. A very thin layer which is chemically attached and is not removed by mechanical dewatering.
_____ Floc water	
_____ Capillary water	B. Contained inside biological cells and is released upon thermal conditioning.
_____ Bound water	
_____ Intracellular water	C. Removed by simple gravitational settling.
	D. Is squeezed out when mechanically compressed.
	E. Adheres between adjacent particles and is removed when particles are forced out of shape and compacted.

11. What accounts for the fuel value in sludge?

_____ A. Total solids

_____ B. Volatile solids

_____ C. % moisture

_____ D. Suspended solids

_____ E. Dissolved solids

12. With regard to the fertilizer value of sludge:

_____ A. It is higher in nutrients than commercial fertilizer.

_____ B. It is high in nitrogen.

_____ C. It is lower in most nutrients than that found in commercial fertilizer.

_____ D. It is equivalent to commercial fertilizer.

_____ E. None of the above.

13. What is (are) drawback(s) to the use of sludge as a fertilizer?

_____ A. Presence of too many nutrients.

_____ B. Presence of pathogens.

_____ C. Presence of heavy metals.

_____ D. A & B are both correct.

_____ E. B & C are both correct.

14. The surface of a sludge particle plays a role in affecting its flocculation characteristics. This is due to:

_____ A. The presence of an electrical charge.

_____ B. The presence of filamentous bacteria.

_____ C. The presence of viable microorganisms.

_____ D. A & B are correct.

_____ E. B & C are correct.